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Ville Nivalainen

Pre-Service Teachers' Objectives, Challenges, and Experience of Practical Work

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ABSTRACT

This dissertation deals with the use of practical work in the context of physics teacher education. The study has been conducted throughout by means of qualitative research.

Study was made of the planning and implementing of practical work by pre- and in-service teachers and a model of the challenges faced by the teachers was formed based on the results obtained. The types of challenges confronting both participant groups were similar, but differences were nevertheless detected when the distinct categories were examined more closely. By gaining an understanding of the categories of challenges represented in the model, teacher educators can provide pre- and in-service teachers with learning situations to realize their own deficiencies.

The pre-service teachers' understanding of the objectives of practical work was investigated and the results revealed which objective categories were well understood and which needed to be paid more attention to in the education of pre-service teachers. The results of the study also contain implications for teacher education programs.

Pre-service teachers' experiences of practical work at school and university were also examined. Examination revealed not only positive and negative experiences of practical work but also the underlying reasons for such assessments. Negative experiences were mainly related to the challenges involved in the planning and implementation of practical work that their previous teachers had experienced, whereas positive experiences were obtained if the objectives of practical work were transparent to students and the means used to examine the phenomena were reasonable and flawless for students. The relations between experiences and challenges were also subjected to discussion.

In the end, all of the results presented in this dissertation are related to the teacher knowledge that can be fostered by taking the implications of the study into account in suitable environments within teacher training programs. One way in which the participants in the program may be provided with opportunities for reflecting on the limits of their teacher knowledge could be the open guided inquiry environment that is described in several of the articles making up this dissertation. The process in which the participants are involved is described and discussed, and the aspects of teacher knowledge that have been developed are described.

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Preface

This study could be described as an interest-driven journey that had actually started before I recognized it as such. The story began after my graduation when I was offered the opportunity to be the instructor on a 'Course of Laboratory Practice for Teachers' (CLP). In addition to the CLP, my intention was first to undertake research concerning the use of the surface-charge theory at upper secondary school level, and later on to study the participants and the process involved in a course of Conceptual Physics. As a result of several misfortunate setbacks (e.g. a lack of students for the course, upper secondary school pupils not coming to interviews, etc.) that were experienced in connection with both of the planned data collections, these studies had to be abandoned and my research plans had to be modified so that I could find a reliable source of data. By that time, I had already organized CLPs two or three times, and both my supervisor and I were convinced there would be untouched areas open to research, including a new formulation of theories related to the intended field.

Even if the completion of my thesis has required a relatively long period of time counting from the start of my PhD studies, I have no regrets about the time spent in the process. I feel that, in addition to the development of my own understanding, new and worthwhile knowledge has been developed in the research published that can be used in developing physics teacher education further.

I wish to express my deepest and warmest gratitude to my supervisors Pekka Hirvonen and Mervi Asikainen for their patient guidance and support throughout this journey and my scientific career. I cannot imagine any better supervisors to exist who really do care for their students and invest so much time in us and keep our faith up. Thank you!

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I am grateful for the financial support of The Finnish Graduate School of Mathematics, Physics, and Chemistry Education. It was a great privilege to work for two years as a full-time researcher and to join the national and international meetings to obtain feedback for my work regularly.

Furthermore, I want to thank the personnel of the Department of Physics and Mathematics for all the scientific and non-scientific activities.

Thank you for all my friends, especially Sami, Minna and Anni for making my weekends and evenings relaxing and making me to forget my work for a while.

I want to express my deepest and warmest thanks to my parents Maisa and Hannu for all your love, everlasting support and faith in me.

Finally, I dedicate my special thanks to Oili for her love and care. Thank you for being there for me.

Joensuu, May 5, 2011

Ville Nivalainen

LIST OF PUBLICATIONS

This thesis is based on data presented in the following articles that are referred to with the Roman numerals I-IV throughout the overview.

I Nivalainen, V., and Hirvonen, P.E. (2008). Teacher students and in-service teachers planning and implementing teaching sequences in the school physics laboratory. E. van den Berg, A.L. Ellermeijer and O. Slooten (Eds.), *Modelling in Physics and Physics Education (pp.* 964-967). Amsterdam: AMSTEL Institute, University of Amsterdam.

II Nivalainen, V., Asikainen, M. A., Sormunen, K., and Hirvonen, P. E. (2010). Preservice and inservice teachers' challenges in the planning of practical work in physics. *Journal of Science Teacher Education, 21(4)*, 393–409.

III Nivalainen, V., Asikainen, M. A., and Hirvonen, P. E. (submitted). Pre-service teachers' objectives and their experience of practical work. Submitted to the *International Journal of Science Education.*

IV Nivalainen, V., Asikainen, M. A., and Hirvonen, P. E. (submitted). The development of teacher knowledge in open guided inquiry laboratory. Submitted to the *Journal of Science Teacher Education*.

AUTHOR’S CONTRIBUTION

The author has participated in the planning of the methods used in the collection of data with regard, firstly, to issues of what kind of data is needed and, secondly, to the way in which it needed to be collected for each of articles I-IV. He has collected and transcribed all of the data, has done all of the analyses to be triangulated by another researcher, and he has played a major role in the writing process of articles I-IV. The role of the author in formulating the theoretical backgrounds used in the articles has developed gradually for each article. Articles I-IV have not been, and will not be, used as part of any other dissertation.

Contents

1 Introduction

My interest in pre-service teachers' experience of practical work developed in the course of my first few years of working at the Department of Physics and Mathematics. After several years during which I taught the Course of Laboratory Practice for Teachers (CLP), I was expected to have acquired a reasonable understanding of what was happening in the course and of the benefits that it could offer for pre-service teachers. There remained, however, quite a lot that was still to be uncovered, and our research group decided to study our pre-service teachers' conceptions and the processes that they were going through both before and during the CLP.

The aim of this study was, therefore, to develop an understanding, on one hand, of the possibilities that practical work could offer for physics teachers in physics teacher education and, on the other hand, to outline the challenges that teachers were likely to face when using practical work as a part of physics teaching. Hence, in order for us to acquire an understanding of these two aspects, the subject group members' conceptions needed to be examined.

A constructivist paradigm (Guba & Lincoln, 2005) is very suitable for this kind of research, which deals with subjects' conceptions. The conceptions are constructed actively by the individuals by means of new subjective experiences that are interpreted based on their previous understanding. Each individual has his or her own, different conceptual framework that affects the concepts constructed. In consequence, even though a conception may be developed in the course of social interaction, such as while doing group work, the individual him/herself constructs his or her own conception based on his/her pre-knowledge. Furthermore, in many cases, such conceptions are not static but they can take a different form, which becomes apparent when the concept is examined in a different context.

As stated above, an individual can express information differently depending on the situation or the context, which in turn will affect the understanding the researcher is able to achieve. Furthermore, all of the conceptions expressed are only partial, simplified reflections of the framework that the individual possesses. It is a challenging, although at the same time typical, aspect of qualitative research to discover the most effective ways in which the data can be acquired. For example, if an interview is the method for being used, a researcher has to be careful in selecting the questions, taking into account the context in which the interview is made, the background of the interviewee, the type of previous and further questions presented in the interview, and so on. Despite the care with which the researcher takes his/her decisions, the data will still form only a partial representation of the interviewee's understanding, which will nevertheless need to be interpreted in one way or another. The data being described, the ontology of the constructivist paradigm, and hence this research as a whole remains relativistic and the epistemology subjective (Guba & Lincoln, 2005).

The methodology used in a constructivist paradigm is hermeneutic or dialectic (Guba & Lincoln, 2005) because of the nature of the data that can be acquired. When the data is gained from dynamically changing conceptions, it is already known before selecting the actual method that the data must be interpreted and expressed and thus it cannot form a description that will include all of the aspects that the subject of such study possesses. Despite this, a researcher has to deal with the results in a dialectic discussion in order to achieve the best attainable interpretations.

In accepting the fact that a researcher can only construct an impression of the subjects' conceptions, a question arises concerning the final credibility of the study. The credibility of the analyses and interpretations is usually increased by using either a triangulation of the sources or analyst triangulation. The first compares the results from different kinds of data sources, whereas the latter compares the analyses of a single set of data put together by two or more researchers (Stake, 2005).

The structure of the present study is as follows. The theoretical background in terms of practical work and teacher knowledge is described in the following chapter. Research tasks, research strategy, context, subject groups, data collection, and analysis methods are introduced in Chapter 3. Chapter 4 provides a brief introduction to the articles included in this study, along with the results achieved, which are then discussed in Chapter 5 together with an examination of the trustworthiness of the study. The conclusions and outlook are then presented in the final chapter.

2 Theoretical background

This research examines the role of practical work in the development of teacher knowledge, and hence the theoretical background can be divided into two parts. The first part introduces the practical work briefly in terms of its objectives and openness. The second part deals with the concept of teacher knowledge, in particular its origins and its development by other scholars.

The theoretical background for the practical work has already been dealt with extensively in articles I-IV and also teacher knowledge in article IV. In consequence, only the most essential topics are presented in this chapter again in order to construct a context for understanding the results of the study as a whole.

2.1 PRACTICAL WORK

The use of practical work has been discussed exhaustively in the literature published in the course of the past four decades (Hofstein & Lunetta, 1982; 2004; Kerr, 1964; Shulman & Tamir, 1973; White, 1996). Its roles and goals have been examined widely, and one can find both support for and criticism of the use of practical work as a part of physics teaching (Klahr, Triona, & Williams, 2007). It cannot be disputed that practical work can have reasonable goals, but it may also raise many questions such as “Does it result in better learning?” and “Which barriers need to be overcome for such education to be introduced in schools?” (Anderson, 2002). Such questions, together with discussion about limited time and space resources and curriculum standards (Bybee, 2000; Fazio, Melville, & Bartley, 2010; Ma & Nickerson, 2006) will be considered in discussions of the use of practical work. Both the positive and the negative sides of the coin need to be understood before practical work can be used effectively.

2.1.1 Objectives and openness of practical work

There are many different ways to implement practical work at any level of education but two defining factors could be outlined here that will guide decisions concerning subsequent practical work. The first is the goal or objective of practical work, which states what is hoped to be achieved by means of a particular activity. The second is the intended openness of the inquiry, which defines the roles of both the teacher and the student.

The research literature in the field has yet to reach a final consensus about the objectives of practical work but several suggestions have been made (American Association of Physics Teachers, 1998; Beatty & Woolnough, 1982; Hofstein & Lunetta, 2004; Kirschner & Meester, 1988; Lynch, 1987; Shulman & Tamir, 1973; Welzel et al., 1998; White, 1996). It could even be claimed that a general consensus cannot be achieved since every situation where practical work is used is different and the desired goals will vary depending on the case. Teachers have to make decisions to select an appropriate type of inquiry to match the aims of teaching (Staer, Goodrum, & Hackling, 1998). In addition, some of the objectives are reasonable to be emphasized at different levels of education.

In the analysis of the related literature in article III the six most central objectives of practical work were outlined, including:

1. Development of practical or experimental skills,
2. Development of an understanding of the science content and conceptual understanding,
3. Fostering of motivation,
4. Development of an understanding of scientific process or scientific thinking,
5. Enhancement of social and learning skills, and
6. Development of an understanding of the nature of science

These six main objective categories consist of several sub-goals and can be considered to be general goals for the use of practical work. The objective categories presented have overlapping aspects, although they are different in nature. For example, the objectives ‘Development of conceptual understanding’ and ‘Fostering of motivation’ are both desirable, although the first is relevant from the point of view of the discipline, while the second serves other purposes even if it supports the learning per se. It is important to concentrate on one or two specific objectives at a time in order to keep practical work focused. The objectives of any experiment have to be chosen carefully before even beginning to plan to use any form of practical work and the function of the practical work has to be justified. The theoretical background of article III discusses the objective categories in more detail and describes some of the debates that take place in the literature concerning the objectives of practical work.

The second factor that is considered when deciding on the type of practical work is the openness of the inquiry (Colburn, 2000; Hegarty-Hazel, 1986). The openness is related to the amount of responsibility in the process of inquiry given to the person who is undertaking the practical work. Hegarty-Hazel (1986) proposed a classification for the inquiry in terms of openness of problem, apparatus, procedure, and answer. The most closed level inquiry is called ‘Verification’, in which the student’s role is to process a given problem, to use the given apparatus, and to follow the given procedures. The answers are predetermined and can be checked from the instructor’s notes if the result is right or wrong (De Jong & Van Der Valk, 2007). This type of practical work is widely used as part of Bachelor level studies at universities. Criticism has been expressed of the fact that activities of this kind frequently occur at school and students are not provided with opportunities to undertake more open-ended experimentation (Hodson & Bencze, 1998). The other extreme of the openness is termed ‘Open inquiry’, in which the student formulates the problem, selects the apparatus and procedure, and ends up with a result that cannot be predicted before the implementation of the experiment. Both of the extremes are used in different situations, and different objectives, as described at the beginning of this chapter, will be set. A closed approach might be useful when teaching the use of a particular piece of equipment, whereas some higher level open inquiry may be a more suitable approach when teaching about the scientific process. Again, a careful consideration of the openness of the practical work needs to be undertaken in order to fit the openness with the objectives that are aspired to.

The aspects described above have been taken into closer consideration in articles III and IV. These two points are important with regard to the discipline, whereas pedagogical skills and knowledge could be emphasized in a different kind of study.

2.1.2 Practical work in teacher education

Practical work that is being done in science departments, especially at the introductory and Bachelor levels, are typically deductive in nature and closed, as described in section 2.1.1, above. Task assignments usually require the use of a particular instrument or method, and the results are pre-determined (Bencze, 1996; Domin, 1999). While this kind of work fulfils the objective of familiarizing the student with the equipment and allows him/her to obtain results that can be reported as for second objective, this type of practical work is insufficient in itself for the needs of pre-service teachers (Cheung, 2007). The literature (Domin, 1999; Hodson, 1992) states that participants in traditional laboratory courses usually concentrate more on the results of their measurements and how they relate to the expected outcomes than on the planning and organization of the experiment itself. The most important lesson for the participants should be to understand why the experiment has been undertaken in the first place (Millar & Abrahams, 2009). Furthermore, there has also been some discussion (Melville, Fazio, Bartley, & Jones, 2008; Zembal-Saul, Blumenfeld, & Krajcik, 2000) of the way in which subject matter knowledge alone is insufficient for teachers. Hodson (1996) proposes that pre- and in-service teachers should be provided with courses that focus on the roles played by practical work, namely to learn science, to learn about science, and to do science.

The research literature suggests pre-service teachers should be provided with opportunities for investigating, planning, and practicing. In this way they could reflect on and reorganize their understanding of the actual science content (Abd-El-Khalick & BouJaoude, 1997; Niess, 2005). The use of open guided inquiry was proposed in article IV as a means of addressing these issues. Nevertheless, even if open guided inquiry might be suitable for pre-service teachers, it must be borne in mind that it may not be as effective for students at school level (Settlage, 2007). For example, Chatterjee and others (Chatterjee, Williamson, McCann, & Peck, 2009) have reported that students' attitudes are more positive towards guided inquiry than open inquiry laboratories in the context of chemistry. In contradiction to this result, it has recently been reported (Sadeh & Zion, 2009) that by using open inquiry students will develop their procedural skills better than by using the guided inquiry approach.

Furthermore, national education standards both in Finland (National Board of Education, 2003; 2004) and in other countries (National Research Council, 1996; 2000) require and emphasize the use of practical work in schools. Being able to use practical work reasonably as a part of physics teaching is challenging (Crawford, 2007), but it is nowadays a requirement for teachers as spelt out in the regulations governing standards. In consequence, teachers need to become familiar with the use of inquiry as a teaching tool (Johnston, 2008; Varma, Volkmann, & Hanuscin, 2009) during their education (Akgul, 2006) or in the course of professional development programs intended for in-service teachers (Wee, Shepardson, Fast, & Harbor, 2007). In order to persuade teachers to use practical work, they need to be motivated to use it, just as some students need to be motivated to become receptive to such teaching (Berg, Bergendahl, Lundberg, & Tibell, 2003). Furthermore, teachers have to believe that students are capable of completing inquiry activities (Cheung, 2007), and both parties have to be committed to the activities (Duran, McArthur, & Van Hook, 2004) and to understand the relevance of the activity (Hart, Mulhall, Berry, Loughran, & Gunstone, 2000; Windschitl, Thompson, & Braaten, 2008; Woodley, 2009) so that the activities can be worthwhile.

2.2 TEACHER KNOWLEDGE

The concept of teacher knowledge is used in this research in describing the aspects of knowledge that a teacher needs in order to be successful in his or her teaching. Further concepts describing similar types of knowledge can also be gleaned from the literature. Verloop, Van Driel and Meijer (2001), for example, have collected various different labels used to describe aspects of teacher knowledge defined by other authors. For example, the concepts of 'personal knowledge', 'the wisdom of practice', and 'professional craft knowledge' all concern aspects of teacher knowledge (Verloop, van Driel, & Meijer, 2001).

2.2.1 The concept of teacher knowledge

When examining the concept of teacher knowledge it is necessary to go back to Shulman's works (Shulman, 1986; 1987). Shulman initiated the study of how teachers' content knowledge and pedagogical knowledge related to each other (Shulman, 1986). He introduced three categories of content knowledge: subject matter content knowledge, pedagogical content knowledge, and curricular knowledge. He continued the work and expanded his idea by introducing the notion of a knowledge base for teachers (Shulman, 1987) in the following year.

This new model (Shulman, 1987) consisted of seven categories that Shulman considered a minimum necessity for teachers to be successful in their jobs. In the same publication he stated that the list in his other publications had not been completely consistent, but he proposed the categories as those to which attention need to be paid.

Shulman's knowledge base for teachers is presented in article IV in somewhat more detail, but the basic categories of the knowledge base are as follows (Shulman, 1987):

1. Content knowledge,
2. General pedagogical knowledge,
3. Curriculum knowledge,
4. Pedagogical content knowledge,
5. Knowledge of learners,

6. Knowledge of context, and
7. Knowledge of educational purposes.

Several scholars have used the concepts related to teacher knowledge loosely even though the concepts have not been defined clearly. The definitions provided by Shulman are not very accurate, and, for example, Ball et al. (Ball, Thames, & Phelps, 2008) state that the term 'pedagogical content knowledge' has lacked both definition and empirical foundation. Furthermore, in their opinion, the relationship between teachers' content knowledge and student achievement should be investigated in more detail to emphasize the aspects that foster achievement the best (Ball, Thames, & Phelps, 2008). Generally it can be stated that the teacher's content knowledge predicts the students' learning outcome as shown, for instance, in the study published by Hill et al. (Hill, Rowan, & Ball, 2005) in the context of mathematics. Despite the lack of a broader empirical foundation, the aspects of teacher knowledge are generally used as norms for achieving successful teaching.

Other researchers have expanded on Shulman's concept of the pedagogical content knowledge (PCK) by including several aspects of the knowledge base in it (Cochran, DeRuiter, & King, 1993; Fernandez-Balboa & Stiehl, 1995; Geddis, Onslow, Beynon, & Oesch, 1993; Grossman, 1990; Hashweh, 2005; Loughran, Berry, & Mulhall, 2006; Magnusson, Krajcik, & Borko, 1999; Marks, 1990; Smith & Neale, 1989; Tamir, 1988). Originally, PCK consisted of two parts: a) a knowledge of strategies and representations, and b) a knowledge of student understanding, namely their conceptions and learning difficulties. A Dutch study concerned with the development of science teachers' PCK (van Driel, Verloop, & de Vos, 1998) lists the scholars' additions to Shulman's PCK. For example, Grossman (1990) reformulated Shulman's PCK by adding educational purposes and curriculum materials to the original two items defined as PCK. Marks (1990), on the other hand, included curriculum and media as well as subject matter knowledge in PCK, whereas both categories were defined as distinct parts of the knowledge base for teachers in Shulman's model (Shulman, 1987). One of the latest models of PCK has been proposed by Park and Oliver (2008), in which PCK includes teachers' understanding of how to teach subject matter effectively in combination with the enactment of their understanding.

As may be assumed, pre- and in-service teachers may have several limitations in their teacher knowledge, which will become visible in their teaching. Framing teachers' PCK, and thus their teacher knowledge, is challenging (Loughran, Milroy, Berry, Gunstone, & Mulhall, 2001; Loughran, Mulhall, & Berry, 2004), but despite this, the problems involved in the knowledge have already been reported in the existing literature. For example, a study by Abd-El-Khalick and BouJaoude (1997) reported on the deficiencies in science teachers' knowledge base. The participants in their study had a non-coherent view of the nature of science, the structures of their disciplines were not elaborate, they had problems in defining the functions of the discipline, and they lacked knowledge of the related alternative conceptions that students have concerning the topics being taught (Abd-El-Khalick & BouJaoude, 1997).

The limitations of teacher knowledge increase greatly in the situation where teaching is given as the teacher's secondary or tertiary subject or when the topic to be taught is studied very little. Such problems have been faced, for example, in Australian schools, where all science subjects are taught in the 'science' classroom and not specifically under the rubric of the distinct disciplines of physics or biology (Harris, Jensz, & Baldwin, 2005). Due to the early distinction into different disciplines, this kind of problem caused by teachers' background is rarely encountered in lower and upper secondary schools in Finland.

Researchers agree that the development of pedagogical content knowledge can begin during the pre-service teacher program and develop in the course of experience acquired in teaching in actual classrooms (Baxter & Lederman, 1999; Gess-Newsome, 1999; Magnusson, Krajcik, & Borko, 1999; Lee, Brown, Luft, & Roehrig, 2007; van Driel, Beijaard, & Verloop, 2001). This research focuses on the possibilities and the role of practical work in initiating the development of physics teachers' teacher knowledge during their teacher education program.

3 Empirical study

This chapter outlines the methodological decisions taken in the present study. First, the research tasks are introduced in the order of their appearance in articles I-IV. Discussion is also reported here concerning the links between the research tasks and the reasons for each task being undertaken. Second, the research strategy is discussed in order to show the stance of the researcher regarding the information that can be acquired. Next, the contexts of the study are described, since their role in this process is undeniable. Furthermore, the participants in the study, namely pre-service and in-service teacher groups, are introduced. Finally, the data collection and analysis methods are described.

3.1 RESEARCH TASKS

This research concentrates on four different topics addressing practical work from different perspectives. It can be stated that the research has been interest-driven because the research questions for each article have been devised on the basis of interests shared by the researcher and his supervisors.

Chronologically, the first task was to gain an understanding of the discussions that took place in the planning of teaching units in which the use of practical work was emphasized. We were interested in what was being discussed mainly when two different subject groups, namely pre-service and in-service teachers were planning practical work for teaching purposes. The research question was therefore set as:

1. "What kinds of issues are addressed in discussions between teacher educators and pre- and in-service teachers when planning experimental teaching units in physics?"

As the research progressed, the challenges faced by pre- and in-service teachers in the planning of practical work became the main focus of that particular study.

The first study provided us with an understanding of the challenges involved in the planning of practical work, but in the meantime new questions had risen. The participants in the Course of Laboratory Practice for Teachers (CLP) were able to prepare experiments for teaching purposes despite the challenges, but what did they think about the practical work involved in this process and why did they make the particular decisions that they did? Their school background and the teaching that they had received there must surely have impacted on their views about the use of practical work. Above all, then, attention needed to be paid to whether pre-service teachers considered it important to use practical work as a part of physics teaching or not. In consequence, a further question was posed:

2. "What kind of objectives do pre-service physics teachers express for practical work when reflecting on their previous experience of practical work?"

In addition, it would clearly be interesting to understand the kind of experience that participants had had of practical work at school and university. Hence, another research question was posed to explore this aspect:

3. "What kind of positive and negative experience do pre-service teachers have of practical work?"

The final research task was to study how pre-service teachers' teacher knowledge was developed during the CLP. This question was also set in order to understand in a more holistic way how pre-service teachers experienced the CLP and what the course actually gave to our pre-service teachers in the end. The aim of this final research task was also that it would function as a summary of the whole study, in the process linking together the results previously gained. The final research question was formulated as

> **4. "How the use of open guided inquiry laboratories initiates the development of pre-service teachers' teacher knowledge in a special laboratory course designed for teachers already at Bachelor level?"**

Investigating the development of teacher knowledge as the final part of this study constituted the end stage on a natural continuum that connected with the previous studies since they had already pointed in this direction.

3.2 RESEARCH STRATEGY

At the very start of the study the author was interested in pre-service teachers' conceptions and in the processes that undergo in their physics teacher education. This interest was especially concerned with courses that included practical work. Hence, the research questions dealt with in this project have been formulated in such a way that, as a result of the research and the interpretations provided, any researcher would be able to understand the conceptions and processes of the subject groups studied. Hermeneutical existential phenomenology, which is to a large extent the research strategy of this dissertation, has provided the appropriate tools for such a study.

Phenomenology is a descriptive strategy that modifies the knowledge or world that precedes the research (Macann, 1993). Macann (1993) describes Merleau-Ponty's views of phenomenology and states that expressions of experience are required in order to separate and understand the essence of each experience. Phenomenology is hermeneutical when the method includes interpretation (van Manen, 2002). Furthermore, phenomenology is existential when attention is paid to how the phenomena reveal their existence in the context under study (van

Manen, 2002). The following few paragraphs describe how hermeneutic existential phenomenology plays a role in articles I-IV.

In articles I and II the principles of grounded theory were adopted for the data collection and analysis. In the present study the analysis of the qualitative data was made without any conscious presuppositions in order to discover what the pre- and in-service teachers were discussing. It became evident while studying the data that the participants had experienced some problems in the planning of practical work, which caused them to ask the course instructor questions. This note concerning further analysis of the data initiated the creation of a model of teacher's challenges in their planning of practical work. In this kind of qualitative study, analysis is hermeneutic since the researcher will always be subjective within his/her own context, and s/he will interpret incomplete quotations of participants' speech or text.

Article III can be divided into two parts, the first one concerned with pre-service teachers' objectives in laboratory work and the second with pre-service teachers' experiences gained in the course of their practical work. For the first part, analysis was done on the basis of the theoretical context. Interpretations of pre-service teachers' essays needed to be produced so that they could be sorted into categories set up on the basis of the literature. During examination of the first research question in article III it was noted that pre-service teachers' experiences of practical work were closely related to the easily distinguishable objectives of practical work, thus producing a new kind of knowledge. The latter part of the analysis was thus more interpretative than the first part and no actual model based on the literature shaped the analysis.

For article IV the theoretical context served as a starting point for the creation of the categories derived from the pre-service teachers' reflective essays and interviews. Again, this kind of data only partially expresses the pre-service teachers' knowledge that is interpreted by the researcher. Having said that, it has to be pointed out that the interpretations of the data were made in order to explain the development of different aspects of teacher knowledge, while the reliability was enhanced by means of researcher triangulation.

In concluding this chapter, it can be stated that in every phase of this research the researcher used qualitative data sources that required the formulation of careful interpretations so that models of the participants' processes or conceptions could be constructed. Some parts of the project were theory-guided, but in other phases new kinds of models were developed based on the data without recourse to any conscious presuppositions.

3.3 METHODS

The methods section is divided into four parts. In the first section the context of the research is introduced. The context is quite unique in comparison with other university environments and hence understanding the context may be regarded as important for a proper examination of the findings reported in the articles and in the discussion contained in this dissertation.

The groups of subjects involved in the study are introduced in the second and third sections. The first group to be introduced consists of pre-service teachers undertaking their teacher education studies at university. Another of the groups consists of in-service teachers who participated on the CLP in 2006 and it was possible to investigate them in the course of their Master studies for in-service physics teachers.

3.3.1 Basic Laboratory Practice for Teachers

Basic Laboratory Practice for Teachers (BLT) is the first of the laboratory courses intended solely for students taking the teacher education program in the Department of Physics and Mathematics at the University of Eastern Finland. BLT is usually taken during the second year of physics teacher education and it is a prerequisite for the CLP described in section 3.3.2. The total earlier experience of practical work that the pre-service teachers had had before the BLT was based on their lower and upper secondary school and also on their studies of traditional basic laboratory work done at university.

BLT deals with the use of practical work at school as a part of physics teaching. Traditional experiments with simple equipment are conducted in small groups while the course instructor guides the participants. The experiments are kept quite simple since one of the objectives of the course is to introduce its participants to the use of practical work with the kind of equipment that is likely to be found in every school. The tasks are given by the instructor to the groups, which then construct the experiment based on the instructions or discuss the reasoning assignment that has been given. Pre-service teachers are asked to explain the phenomena to their peers while working on the given tasks, which sometimes reveal alternative conceptions of phenomena that can then be discussed further.

In the course of BLT, perspectives on the study of physics in some senses change. In the past, pre-service teachers completed laboratory courses in order to construct their own content knowledge in the subject, and they also learnt the way in which reporting is conducted in physics. In contrast, the focus of BLT (and CLP) is also on other aspects. The participants are required, for example, to consider carefully the ways in which physics could be presented with the aid of practical work to lower and upper secondary school students.

The aim of the course related to this research is to activate participants to think about physics teaching, since within as little as three years' time they are likely to be employed as physics teachers. Furthermore, the school background of each pre-service teacher is different and by no means all of them have previously dealt with any practical work, while, in contrast, some of them will already be familiar with traditional experiments.

The course instructor plays a central role in assigning tasks, guiding the discussions, and providing final explanations of the phenomena and experiments involved in the course. BLT prepares pre-service teachers for greater responsibility in their planning of the practical work that they are assigned in CLP in terms of selecting problems, equipment, methods, and explanations.

3.3.2 Course of Laboratory Practice for Physics Teachers

The Course of Laboratory Practice for Physics Teachers (CLP) has been presented extensively in article II. However, since the course is the context for most of the project, it deserves to be described in a little further detail. In this description the participants are pre-service teachers, since the CLP has been designed primarily for them, but it has also been used in a "Masters studies for in-service physics teachers" program, which appears in section 3.3.4.

The CLP has been organized and developed for more than ten years and it has been a mandatory part of physics teacher studies throughout that period. Pre-service teachers usually take the course after completing most of their theoretical physics courses and before commencing their periods of teaching practice organized by the University Practice School. Generally this means that second- and third-year pre-service teachers take the same course together, depending on their major subjects and on their personal curricula.

The aims of the course are threefold. The first is to help pre-service teachers to understand the purposes of practical work as a part of physics teaching. At the beginning of the course, pre-service teachers may have only a limited view of the possible objectives of practical work and of the various ways to organize practical work at school, but these aspects are likely to broaden during the course.

The second aim of the course is to provide pre-service teachers with opportunities to learn more about the structure and content of physics in addition to the theoretical courses that they have already completed. The pre-service teachers are offered a new context and fresh perspectives for examining physics theories before they start on the teaching practice. In additon, as an implicit goal, pre-service teachers are also expected to learn how to transform their scientific knowledge for teaching purposes, not only while studying the actual content but also by experiencing different implementations in a given context.

The latter aim has been designed in order to provide pre-service teachers with an introduction to two instructional approaches, namely modeling and the perceptional approach. Modeling has been the main instructional approach used in connection with physics in the national curricula since 2003 (National Board of Education, 2003; 2004), whereas the perceptional approach was used in earlier physics curricula (National Board of Education, 1994a; 1994b). The idea about a specific instructional approach that will guide a teacher in his/her selection of the most effective and coherent ways to present physics to pupils is presented to pre-service teachers for the very first time.

The course, the schedule of which is shown in Table 3.1, starts with introductory lectures dealing with the very basics of the instructional approaches mentioned above. Later, course participants are encouraged to make their own decisions about whether they wish to use either of these approaches in their presentations. From time to time, participants are also reminded that a teacher needs a coherent plan for his/her teaching and the use of any experiment has to be justified.

Table 3.1. The schedule for the CLP in the case of pre-service teachers

Week 1	Opening lectures: instructional approaches, the use of computer-based systems
Week 2	Laboratory exercises to introduce computer-based systems. Conceptual map-making related to the topic.
Weeks 3-4	Planning phase in the laboratory
Week 5	Presentations (60min/group)
Week 6	Reporting and making concept map for the 2nd round
Weeks 7-8	Planning phase in the laboratory
Week 9	Presentations
Week 10	Reporting

The use of computer-based measurement systems also forms a topic of discussion in the lectures since the participants have the possibility of using the appropriate equipment. Participants are usually familiar only with the traditional laboratory apparatus that they have seen at school, and hence this kind of knowledge has to be addressed. Again, it is up to the pre-service teachers themselves to decide whether they want to use such methods in their presentations or whether they prefer traditional means of data collection and analysis. Their introduction to data-loggers continues in the laboratory in the form of a few simple measurements. The data is collected by sensors and analyzed further using software. This kind of introduction is intended to provide pre-service teachers with the skills required to use computers in their future gathering and analysis of data and analysis and also to widen the available means involved in deciding how they would wish to represent their ideas in presentations made later in the course.

In the next phase, the pre-service teachers adopt a more active role and greater responsibility when they begin planning practical work that would be suitable for upper secondary school. Small groups consisting of two or three pre-service teachers are given a very broad topic such as 'thermal physics', which they have to process further. First, they examine the structure and content of the topic and produce a concept map related to their topic. The purpose of creating a concept map is to help them to focus on the most important concepts that they would want to concentrate on in the experiments. Two school textbooks are given to the groups as support material to help them to begin examination of the structure of their subject. It is also emphasized that they should pay an attention to the national curricula when deciding which concepts they are finally concentrating on. They are required to explain later why a particular experiment should be used as a part of a teaching sequence in a physics course, and how it relates to previously understood concepts.

In this phase, greater responsibility is given to the pre-service teachers. The groups have to plan and implement a 60-minute teaching sequence concerning their topic where the use of practical work plays a central role. Depending on their particular interests, the participants may decide which concepts or phenomena they want to focus on. They may also select the equipment they want to use and decide on how to analyze the results. After creating a concept map and selecting the concepts they intend to examine, they have the freedom to construct any kind of experiment they want in order to illustrate their chosen concepts.

In the subsequent two weeks (see the course schedule, Table 3.1.) they come to the University Practice School laboratory to test, refine, and modify their ideas concerning the way in which they can be presented to others. Each group is allotted nine hours of laboratory time for use of the laboratory facilities, in addition to whatever time they also use outside the university. It is suggested to them that the laboratory time should be divided quite evenly in the two week period so that they will have time to revise their plans between the laboratory sessions, where the course instructor will provide any extra advice that may be requested. How efficiently their time is spent in the laboratory depends largely on the participants themselves, since the work that they do before commencing the actual laboratory sessions will help them significantly in actually getting the experiments to work in the way that they anticipate. In the first laboratory session the groups usually familiarize themselves with various items of equipment to be used for their chosen topic. They may test some of the equipment and further refine the ideas that they had developed previously. Most of the changes made at this stage are motivated by their perception that an experiment may be less than ideal, too ambitious, or even impossible to demonstrate solely with simple equipment. In some cases, participants may not have prepared well enough for their first laboratory session and hence they will have to process their topic before they develop ideas for subsequent implementation.

In the course of these two weeks the participants will hold many discussions, in small groups, about the physics content, the possibilities for doing practical work, and the practical issues involved in laboratory implementation. As stated above, this phase of the course can be referred to as open guided inquiry, 2b in Hegarty-Hazel's (1986) ranking (see Table 1 in article IV), and advice is given only if requested. Most questions are related to the challenges encountered in planning and implementing the practical work as presented in article II. In the case being examined, the objectives of an open guided inquiry are different from the teaching that takes place at school level. At school the main objectives are likely to be the development of subject matter knowledge and of an understanding of the nature of science, whereas the development of teacher knowledge is the ultimate goal of the university course for pre-service teachers.

The presentations are given after the conclusion of the two-week planning period. Each presentation takes 60 minutes, during which between one and four experiments are dealt with either as demonstrations or, preferably, as learner-oriented hands-on activities. Generally, the participants describe their topic and present a brief introduction of the concepts that their students are already familiar with, before explaining how their first experiment fits into the curriculum. The presenting group acts as teachers in the classroom, while the other course participants play the role of upper secondary school students. The roles are certainly somewhat unclear, with the result that a lot of peer discussion takes place between the 'teachers' and 'students' in each of the teaching units. In many cases the 'teachers' propose similar theory-related questions to those suggested by the 'students', since they have had to consider such matters carefully in the planning phase of the course.

After the conclusion of a particular experiment, the presenting group leads the discussion about the results obtained and also about ways in which the experiment might be improved. The suitability of the experiment for school purposes is discussed and, perhaps of paramount importance, discussion is turned to the question of what would be the next phase in the teaching at school and how it would relate to the experiment that has just been conducted. By this means, the experiments can be linked both to students' pre-knowledge and also to forthcoming lessons. The role of the course instructor in this is to promote the discussion by proposing new questions and by making remarks about the implementation of the experiment as a whole.

The first working round ends with a reporting week. The participants are required to report once again on the use of various theories of physics and their implementation. On this occasion, however, discussion of the theory is made at introductory university level. The participants write up the theory related to the topic that they have been dealing with and reflect on the experiments they have undertaken, in the process of which they define the links between the experiments and the theory. In addition, the participants reflect on the process of planning and implementing their teaching unit and they propose potential developments. The planning-implementing-reporting round can then be repeated with new topics. By this second stage, participants have usually developed a good understanding on the possibilities of practical work, so they are generally able to produce more sophisticated ideas about the second implementation. The discussions held in small groups also tend to be different in the second round, with the participants taking into account more aspects related to teaching the topic when planning fresh experiments.

As a result of this two-round course, participants will have examined a reasonable number of physics experiments, they will have related them to theories and the curriculum, and they will have discussed the suitability of using experiments at school. In addition, as a result of using open guided inquiry, they will have seen a variety of ways of presenting physics experiments and explanations in the laboratory, and they will now be able to start to refine their own personal ways of carrying out such tasks forthcoming teaching practice periods.

3.3.3 Pre-service teachers

All of the pre-service teachers who participated in any of the phases of this research were taking the BLT and CLP as part of their teacher education. The typical distribution of participants on both courses is approximately two-thirds mathematics and one third physics majors, together with a handful of other major subject students who all will eventually become physics teachers with combinations of other subjects. There were two groups of pre-service teachers who participated in the studies presented in the articles. The first group of 18 pre-service teachers participated in the CLP in 2005, while the second group of 32 pre-service teachers took the BLT and CLP in 2009. The data gained with the first group was analyzed for articles I and II, and the data gained with the second group was used for articles III and IV.

3.3.4 In-service teachers

The Course of Laboratory Practice for Physics Teachers was also provided for in-service teachers in 2005 and 2007 as part of a program under the rubric of "Master's Studies for In-service Physics Teachers". The program participants had had between 3 and 20 years of teaching experience at school, and they had either mathematics or chemistry as their major and physics as a minor. The in-service teachers were completing their Master's studies in physics in order to broaden their expertise in that particular field. Completion of Master's studies would allow them to apply for physics teacher posts at school, a consideration that motivated some of the younger teachers in particular. For the more experienced in-service teachers the completion of the studies served other purposes. Generally speaking, they wanted to acquire something new to enhance their ongoing teaching, such as new ways to present physics in the classroom. The CLP was one of the physics courses included as part of their didactics studies designed to update their understanding of the potential of conducting practical work using the kind of equipment available nowadays. The data received from the in-service teachers attending the CLP in 2005 was used in articles I and II.

3.3.5 Data collection and analysis methods

The principles of grounded theory (Strauss & Corbin, 1990; Charmaz, 2005) were adopted for the collection and analysis of the data used in articles I and II. As described in section 3.1, we were interested in the discussions that took place in the environment of the open guided inquiry when the participants in the CLP were planning practical work. In consequence, it was decided that the course instructors would carry recorders with them in the laboratory and analysis of the data gathered by this means would probably reveal something interesting. The data was gathered in two phases. The first phase involved in-service teachers, while the second phase focused on pre-service teachers, since the CLP was presented to both subject groups separately. Two instructors were involved in the gathering of data from the in-service teachers, while one was involved in the case of the pre-service teachers. The data was analyzed by open coding (Strauss & Corbin, 1990), and researcher triangulation was used to ensure the credibility of the study. Finally, since there was the intention to use grounded theory, a model of the challenges confronting teachers in planning practical work was generated based on the results.

In order to stimulate answers to the research question 2 described in section 3.1, mid-way through the course of Basic Laboratory Practice for Teachers the pre-service teachers were asked to write a reflective essay about their view of practical work. Since we were interested in obtaining data from all the pre-service teachers at a stage in their studies when they had completed almost all of their Bachelor-level theory courses and traditional laboratory courses, use of reflective essays as a data collection method was regarded as reasonable. The topic of the essay was 'Practical Work as a Part of Physics Teaching at School and University'. The pre-service teachers were asked to consider the physics teaching that they had undergone both at school and at university. Based on their experiences, they were asked to reflect on the differences in physics teaching at lower and upper secondary school and to discuss the use of practical work in general. They were also asked to write freely about their own impressions of practical work.

Theory-guided content analysis (Krippendorff, 2004; Neuendorf, 2002) was used to categorize selected extracts from the essays in order to discover the nature of the objectives that the pre-service teachers outlined. In the process of categorization, it became evident that some of the objectives of the practical work that the subject group had already understood at school level had made a positive impact on their motivation to perform practical work and generally to learn physics. Finally, another researcher double-checked our analyses, thus improving credibility of the analysis.

Our note concerning the positive and negative effects on motivation, made in the course of the first categorization, then caused us to consider research question 3, described in section 3.1. In consequence, a second content analysis was conducted in order to sort the extracts of the essays into categories showing what had had either a positive or a negative impact on the subject group. Another researcher checked the analysis, after which one part of the analysis was repeated because the results suggested that a new category was required in aid of the final interpretation of the data.

Research question 4, described in section 3.1, was dealt with in article IV. There, as reported in this dissertation, the reflective essays were used again, along with the interviews that had been conducted with three pre-service teachers. On this occasion the reflective essays were set and written after the CLP. The topic prescribed was 'The Objectives and Challenges of Practical Work'. The teachers were asked also to write about their learning of practical work and about the objectives that they considered important, especially with regard to the use of practical work as a part of teaching at school level. In addition, they were also asked for their impressions of the planning and implementation of practical work in small groups, and also their opinions of their preparedness to use practical work at school.

In order to have another data source and greater credibility for the results and analysis, three pre-service teachers were interviewed. All of the interviews used were semi-structured (Gillham, 2005; King & Horrocks, 2010). The first interview was conducted before the CLP, while the second was conducted after the first planning phase of the CLP but prior to its implementation. The third time that the pre-service teachers were interviewed was on the day after the implementations, while the final interview took place after the conclusion of the course. The themes of the interviews are described in greater detail in article IV.

Theory-guided content analysis (Krippendorff, 2004; Neuendorf, 2002) was again used for both of the data sets. A theoretical background of teacher knowledge was considered sufficient for analysis of the data. Such a background enabled us to place extracts from both the essays and the interviews in categories representing the development of teacher knowledge.

4 Overview of the articles

The articles included in this dissertation are presented below. The purpose of this chapter is to introduce the main results in brief, while a broader examination and discussion of the results have been presented in articles I-IV themselves.

I. Nivalainen, V., & Hirvonen, P. E. (2008). Teacher students and in-service teachers planning and implementing teaching sequences in the school physics laboratory. In E. van den Berg, A.L. Ellermeijer & O. Slooten (Eds.), *Modelling in Physics and Physics Education (pp.* 964–967). Amsterdam: AMSTEL Institute, University of Amsterdam.

In this study the discussions between the instructor and course participants were examined in the context of a course dealing with practical work. The discussions were recorded and analyzed so that we could gain an understanding of the varieties of discussion that took place in such environment. The analysis revealed the types of challenges that pre- and in-service teachers faced in the planning and implementing of practical work. For this article, the four main categories represented: the limitations caused by the laboratory, an insufficient understanding of physics content, an inability to apply instructional approaches in practice, and challenges confronted in organizing the practical work. Further examinations of the data were made later and the results led eventually to article II.

II. Nivalainen, V., Asikainen, M. A., Sormunen, K., & Hirvonen, P. E. (2010). Preservice and inservice teachers' challenges in the planning of practical work in physics. *Journal of Science Teacher Education, 21(4)*, 393–409.

This study followed on from article I by introducing subcategories for the challenges faced in planning and implementing practical work. Four main categories and eleven subcategories were distinguished in the data. Pre-service teachers' challenges were usually related to subject matter knowledge in physics, whereas in-service teachers faced problems with new types of laboratory facilities. As a result of the study, a model of the challenges faced in planning and implementing practical work was created.

The category of the limitations of laboratory facilities consisted of five subtopics. In some cases, the participants encountered problems because of the insufficient quantity of equipment that was available. On the other hand, they sometimes had even too many ways to implement an experiment, which led to discussions focused on the optimum equipment for conducting an experiment. Generally speaking, the use of equipment constituted one of the challenges posed by the course, combined with the problems encountered in extracting the data from the measurements once the participants had understood what could actually be measured.

The participants faced three types of challenges related to their knowledge of physics in general. The first and greatest challenge, which was reflected in the number of quotations, concerned their understanding of the phenomena of physics. The second was related to their ability to limit their topic in terms of planning, and the third consisted in their skill in interpreting graphs.

The challenge faced in gaining an understanding of instructional approaches was regarded as a distinct category due to its difference from the others. The last of the main categories, challenges encountered in the general organization of practical work, consisted of two parts: the participants' ability to organize their students and their ability to organize the actual experiments.

III. Nivalainen, V., Asikainen, M. A., & Hirvonen, P. E. (submitted 2010). Pre-service teachers' objectives and their experience of practical work. Submitted to the *International Journal of Science Education.*

The aim of this study was to seek understanding of the kinds of objectives of practical work that pre-service teachers would emphasize based on their school backgrounds. They were asked to write an essay that was subsequently analyzed in order to reveal the kinds of objectives that they considered achievable by means of practical work. The study revealed not only their objectives but also the reasons for their positive and negative attitudes that they formed at school to the use of practical work.

The objectives of practical work that the pre-service teachers expressed were categorized on the basis of suggestions given in the literature. The pre-service teachers emphasized most the role played by practical work in the development of content knowledge, while the categories of fostering motivation and learning practical or experimental skills played a smaller role in their priorities. On the other hand, the number of references made by the pre-service teachers that fell into the categories concerned with developing an understanding of scientific process, developing an understanding of the nature of science, and the enhancement of social and learning skills remained fairly low, even though these categories existed.

The pre-service teachers' positive and negative experience of using practical work could be interpreted from the essays when they described the practical work that they had experienced at school. The positive experiences were related to the desired objectives of practical work, whereas negative experiences were usually the result of the inability of the teacher to organize the practical work properly. This result was connected with the challenges posed by the planning and implementation of practical work, as seen in articles I and II.

IV. Nivalainen, V., Asikainen, M. A., & Hirvonen, P. E. (submitted 2010). The development of teacher knowledge in open guided inquiry laboratory. Submitted to the *Journal of Science Teacher Education.*

The last article deals with the development of teacher knowledge in the context of practical work. The data was collected by means of essays that were assigned after the open guided inquiry course where the pre-service teachers were required to plan and implement practical work for school purposes. In addition, three pre-service teachers were interviewed four times at intervals during the course.

Starting from the inaccuracies in the pre-service teachers' subject matter knowledge, it was noted that the role played by the small group discussions was extremely important for further development. The discussions helped the pre-service teachers to understand physics to a greater degree, indicating a number of potential alternative conceptions that their future students might have, and stimulated consideration of the optimum ways in which physics content could be presented for such an audience. Discussions of this kind could not take place without the availability of the given context, where the pre-service teachers needed to reason anew their grasp of the physics content so that ways could be found to express it through the use of practical work. In other words, the participants had to reprocess their understanding of physics content in order to be successful in transforming it for teaching purposes.

Several components of teacher knowledge were identified for development in the course of open guided inquiry, and more than half of the participants claimed that their attitudes had developed in the course of using practical work and they agreed about its importance as a component part of physics teaching.

5 Summary and discussion

There are many decisions that schoolteachers in Finland have to make. As a consequence of the open nature of the curricula of lower and upper secondary schools, teachers have considerable freedom and responsibility in considering the best ways to present the knowledge that they decide to deliver to their specific audiences. Teachers' personal background, their previous experience, the available teaching materials and facilities all play important roles in their decision-making. For teachers to be able to make reasonable decisions concerning their teaching, they need to understand thoroughly the aims of their teaching and the possibilities that can be used in delivering the requisite knowledge. This understanding can be supported in teacher education programs by offering pre-service teachers opportunities to reflect on their understanding of the discipline and also to discover the most suitable ways of instruction that will enable them to match their content teaching with their personal styles. The results of this research demonstrate how the development of teacher knowledge can be initiated and fostered by the use of practical work in physics teacher education and how experience gained at school level are reflected when this knowledge is under construction.

5.1 EXPERIENCE OF PRACTICAL WORK

In all educational situations learners come with their previous experience and pre-knowledge. Our teacher education program is no exception: all of the participating pre-service teachers begin the program with their own personal experience of teaching. This background is inevitably various, and participants reveal their previous experience of many different styles of teaching in physics and the other sciences. Their upper secondary school physics teacher may have presented physics using various forms of representation; he or she may have demonstrated the phenomena of physics by means of experiments and motivated his/her students to learn physics by emphasizing the importance of understanding science in general. In some cases, teachers have been devoted to theoretical investigation of physics and have rarely used practical work. Each approach may be preferred by different groups. In a study that eventually led to the writing of article III, two kinds of pre-service teachers could be identified: one group enjoyed the use of practical work, while the other preferred to pay greater attention to theoretical investigation of physics. When participants reflected on their earlier studies, they either stated that pure theory-based teaching was too abstract at school level, or they liked that kind of instruction precisely because of its accurate and precise nature. Similarly, the subject groups' attitudes to the use of practical work differed prior to their attending the BLT and CLP, but later many of them had refined their conception of the roles played by practical work and theory-based investigation, as can be seen in article III.

The results of article III deal with the positive and negative experiences that pre-service teachers had gained at school when practical work had formed part of their studies. The results show that students are able to distinguish between successful and inadequate experiments quite easily. According to our results, the success of an experiment rests on at least two elements: 1) the purpose of the experiment, and 2) the actual performance of the experiment. If both of these elements have been set down and implemented successfully, experiments had generally helped students to learn something new. On the other hand, if the participants in the study noticed problems in either aspect of the experimentation, their perceptions of the practical work were less positive. In some cases, the aims of a particular experiment had been clear but problems occurred in its implementation, causing the experiment to fail to yield reasonable results for analysis. On the other hand, there were also cases in which the experiment worked as planned but the students did not properly understand why the experiment had been conducted in the first place. The results reported in article III nevertheless represent a larger number of positive than negative experiences of the use of practical work at school level. In many cases, positive experiences resulted from a proper understanding of the aims of experiments whose performance had been successful.

As the results of article III show, the subject group also reported a considerable number of negative experiences of the use of practical work at school level. This, in turn, poses the question of how students other than these future teachers also reacted to the use of practical work in the same classes where problems occurred. Despite such noticeable problems, the members of our subject group had still selected physics as their future career, but our present research tells us very little about the impact of inadequate teaching on others. It might be assumed that unsuccessful experiments would not have convinced all of the students of the importance of experimental study, and such failures may even have detracted from the importance of learning physics per se. In a very real sense, therefore, this may have a negative impact on the number of students choosing careers in science.

What, then, are the causes of the failures in experimentation described above and why is it therefore challenging to promote the use of practical work in the classroom? Further, how can similar problems be avoided in the future and what needs to be taken into account when practical work is planned? Indeed, why should practical work be used at all? These questions are discussed in the following sections based on the results achieved in this study.

5.2 CREATING MEANINGFUL EXPERIENCES BY MEANS OF PRACTICAL WORK

In order to make practical work meaningful goals need to be set for each experiment to be presented, as described in section 2.1.1. A few of the objectives of practical work are easily distinguishable, as was found from the results published in article III. The subject group of pre-service teachers stated that practical work could be used to foster understanding of the relation between theoretical knowledge and practice. The finding is similar to the results presented in the earlier literature (Angell, Guttersrud, Hendriksen, & Isnes, 2004; Pekmez, Johnson, & Gott, 2005; Welzel et al., 1998). Furthermore, the pre-service teachers found that the use of practical work motivates students to learn physics, and hence creating motivation could be one of the aims of using practical work. Learning to observe and learning to report scientific results form part of the development of practical skills and were also one of the most frequently emphasized topics. Both of these findings are also considered important in the earlier literature (Wilkinson & Ward, 1997). These three objective categories were more immediately visible than the other aims of practical work in the results of article III.

When the results are looked at more closely, the aims that the pre-service teachers did not mention so readily were related to developing an awareness of the nature of science, to developing an understanding of scientific process, and to enhancement of social and learning skills. As described in section 2.1.1, these objectives are widely accepted as important aims practical work, but they are less easily identified without a prior general understanding of the categories. This finding is also in line with previous research (Lederman, 1992; Schwartz, Lederman, & Crawford, 2004; Wilkinson & Ward, 1997). In many cases, it became clear that the pre-service teachers did not possess the language to express these goals, or that these categories were not considered as important as learning the content and motivating students to learn it. It is, then, a challenge for teacher education programs to emphasize the role played by these important goals so that they can be included in practical work at school level.

Creating meaningful experience that includes the diverse goals related to the use of practical work can be challenging for a new teacher at the start of his/her career. Even if a teacher knows the objectives that he or she is hoping to achieve, there might still be problems involved in actually taking them into account in the planning and implementation of the practical work. Once the desired goals have been decided on, the next stage will inevitably consist of planning the best way to deliver the requisite knowledge to students, each stage posing new challenges. The roles played by such challenges in the context of teacher education are discussed in the following.

5.3 THE DEVELOPMENT OF TEACHER KNOWLEDGE IN THE PURSUIT OF MEANINGFUL EXPERIMENTS

The open laboratory context introduced in articles I and II opens up opportunities for pre-service teachers to discuss their understanding of physics and physics teaching. At this stage the conceptual framework of physics has generally still not developed to a sufficient level for the participants to be able to engage in fruitful discussions with their peers. Discussions of the content demonstrate to pre-service teachers one of the first obstacles that will be encountered in the planning of meaningful experiments: an inadequate understanding of the subject matter itself. Understanding the level of their subject matter knowledge by means of with the handful of alternative conceptions that they have come to possess after taking all of their theory courses is initially a cause of dismay for many pre-service teachers. But after the first shock, and by participating in the discussions, they begin to reconstruct their physics framework and become more confident about their understanding of physics. This result is in line with related literature, which suggests that conceptual progress in scientific thinking can be facilitated by verbalizing learners' own ideas, by formulating and testing hypotheses, by testing thinking through practical work, and by reviewing thinking in light of empirical evidence (Parker & Heywood, 2000).

Participants also discovered similar deficiencies in their peers' reasoning, which permitted them to understand that others may also have problems in their thinking. By understanding the problems in their own and also their peers' thinking, pre-service teachers become aware of some of the possible alternative conceptions that their future students may have. Understanding of alternative conceptions can then be broadened later by means of the introduction of some of the literature dealing with students' conceptions, but the process is initiated by gaining an understanding of the difficulties of the subject or the problems that their peers may possess. Even though an inadequate understanding of subject matter knowledge is one of the challenges involved in the planning of practical work, as reported in articles I and II, it is nevertheless a useful factor to become conscious of, as reported in the article IV. In this sense, the results of articles I, II, and IV supplement each other, and all supports the findings of Van Driel, De Jong and Verloop (2001), who state that the development of pedagogical content knowledge (PCK) becomes possible when subject matter knowledge develops to a sufficient level. As the knowledge of learners is one of the categories of the PCK, this already holds true at this stage.

The other challenges involved in planning and implementing practical work are still to be faced even the pre-service teacher has become familiar with the subject matter knowledge, which is a prerequisite for planning a successful session of practical work. As reported in articles I and II, pre-service – and even in-service – teachers face particular challenges in the form of laboratory facilities, the organization of groups and equipment, and the instructional approach.

Understanding the challenges of planning and implementing practical work can be considered to be a development of teacher knowledge. For example, by understanding the challenges related to laboratory facilities, a pre-service teacher becomes aware of the requirements of a suitable context and adequate equipment in the implementation of practical work at school. By considering their students' pre-knowledge and the specific topics that need to be taught next in the context of their overall topic, pre-service teachers need also to understand the aims set out in the curriculum. Furthermore, if a participant has experienced problems in constructing a coherent implementation of a given physics topic, he/she will need to consider again whether the topic might have been represented more efficiently. This may also work the other way round, as reported in article IV: by experiencing well-organized teaching units and by reflecting on their success, the pre-service teacher will develop understanding, more specifically by developing his/her teacher knowledge, of how to use practical work efficiently at school.

When pre-service teachers are provided with opportunities to re-examine their thinking in a new learning situation, as suggested in the related literature (Abd-El-Khalick & BouJaoude, 1997; Kolb & Kolb, 2005; Niess, 2005; Tillema, 1998) their teacher knowledge will definitely have been enhanced. Re-examining such thinking stimulates pre-service teachers' ideas about effective approaches to practical work at school, even though the process of becoming a teacher per se may still be at an elementary stage.

To collate and summarize the results of articles I- IV, a model is outlined in Figure 5.1. The model combines the challenges that have to be dealt with so that the development of teacher knowledge can be initiated. The challenges of planning and implementing practical work are represented as the outer shell of the inner circle of teacher knowledge. The segments of teacher knowledge shown here are similar to those that Shulman (1987) presented as the knowledge base for teachers. In light of the results obtained in the research undertaken for the present dissertation, there is evident agreement with the literature (van Driel, De Jong, & Verloop, 2001) that subject matter knowledge has to be developed to a reasonable level so that an individual's pedagogical content knowledge can then also develop. This relationship can be expanded and taken further: in the process of displaying and reorganizing subject matter knowledge in an appropriate environment, development of several aspects of teacher knowledge will also occur.

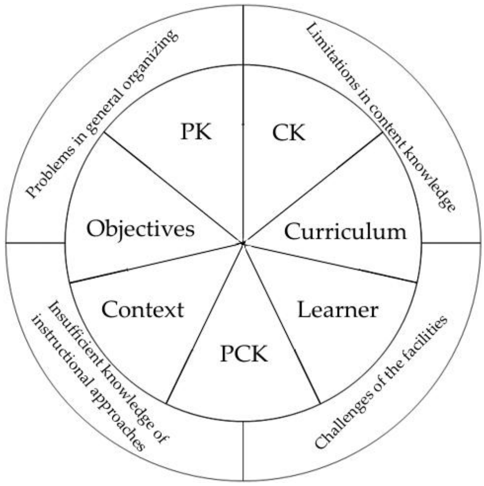

Figure 5.1. Teacher knowledge and the challenges involved in planning and implementing practical work. Abbreviations: PK = Pedagogical Knowledge, CK = Content Knowledge, PCK = Pedagogical Content Knowledge

Pre-service teachers need to become aware of the possible challenges involved in planning and implementing practical work. If pre-service teachers are required to face such challenges in an open guided inquiry environment, they can identify and begin to develop the aspects that they need to overcome in order to be successful in constructing meaningful experiments at school. Understanding their own and their peers' deficiencies in subject matter knowledge will help them to identify the problems that may be faced by their future pupils at school. Furthermore, by comparing the ways in which different kinds of experiments deliver understanding, they will begin to identify the approaches that may work best in the classroom and also which goals need to be achieved in the first place. Small group discussions are the key to understanding the various challenges and possibilities of using practical work. Participants will display their experiences from their own school time and discuss how the use of practical work may very well promote learning better than they themselves have experienced. Thus, all of such discussions and the consequent enhanced understanding of their own limitations will help construct better teacher knowledge.

5.4 TRUSTWORTHINESS OF THE STUDY

According to Lincoln and Guba (Lincoln & Guba, 1985; Guba & Lincoln, 1989), the trustworthiness of the study can be ascertained in light of four criteria. These criteria are generally referred to as the credibility, transferability, dependability, and confirmability of the study.

5.4.1 Credibility of the study

Credibility is related to the confidence of the results achieved in the study. Lincoln and Guba (1985) described seven different techniques for establishing the credibility of research. In 1) Prolonged Engagement, a reasonable amount of time is spent in the field in order to understand the phenomenon of interest providing the scope of the research. The depth of the study comes from 2) Persistent Observation, in which the most relevant characteristics and elements are considered regarding the issues under investigation. The consistency of the results is then evaluated in the 3) Triangulation. Triangulation can be performed by comparing data obtained by different methods, by comparing analyses from different data sources, by comparing analyses produced by different researchers, or by comparing analyses produced from different perspectives. In 4) Peer Debriefing, the researcher exposes his or her analysis to an independent peer, thus offering an opportunity for bias to be revealed and for the underlying hypotheses to be tested and, if necessary, defended. 5) Negative Case Analysis refers to examination and discussion of any items of data that do not support the explanations emerging from the main data analysis. By using 6) Referential Adequacy, the researcher archives some of the data, which can then be analyzed after the preliminary findings have been completed. The analysis of archived data may validate the analysis of the main data at a later stage. The last technique that can be used to establish credibility is 7) Member-Checking. The data analyzed to produce interpretations and conclusions can be given to the participants in the study to discover whether the interpretations strike them as valid. This process may help to reveal the reasoning underlying actions, but it may also cause problems if the participants have forgotten their actions or if they regret some of the answers or interviews that they have provided earlier.

With regard to the whole study reported in this dissertation, the researcher has participated for eight years in teacher training dealing specifically with practical work related to the studies reported here. He would, in consequence claim that, in the process, he has formed a reasonable understanding of its context. Numerous discussions have taken place between the researcher and participants of teacher training courses in the reported context. Hence, it may be suggested that the researcher has achieved a good understanding of both the problems and the potential of participants across a long period of time.

Analyst triangulation was used in several phases of this dissertation project to see whether the data that had been gathered might be interpreted differently by another researcher. Triangulation of sources was used in article IV, where the findings from the essays and interviews were compared. As described in the articles and in the methods section of this investigation, some form of triangulation has been used in all the studies constituting this dissertation.

Throughout the research process, peer debriefing was used to obtain feedback (Kvale, 1996). The researcher was privileged to attend many national and international meetings of researchers and research schools where the ideas, methods, analysis, and discussions were examined critically by his peers. For example, the researcher has been able to participate several times in the Joint Graduate School Meetings, where a peer-review procedure is used in the discussion of papers written by researchers in the broad field. The participants in the Joint Graduate School Meetings are PhD students and their supervisors from Finland, Germany, the Netherlands, Sweden, and Estonia. In addition to participating in the meetings of the graduate school, the researcher has also presented early versions of his research at international conferences organized by the American Association of Physics Teachers (AAPT), the Groupe International de Recherche sur l'Enseignement de la Physique (GIREP), and the European Science Education Research Association (ESERA), each of which has also provided the opportunity for valuable feedback.

5.4.2 Transferability of the study

Transferability describes the possibility of applying the findings of research in a new context. Lincoln and Guba (1985) have proposed the use of a Thick Description of the phenomenon in order to achieve external validity for a study. The role of Thick Description is to provide readers with an understanding of the phenomena under study and to make it possible for them to implement similar tests or studies in their own contexts.

The context and the subject group are described in detail in this dissertation and in articles I-IV. Hence, it can be assumed that the study or selected elements of it may be quite easily transferable to new contexts and groups.

5.4.3 Dependability of the study

Dependability refers to the extent to which the results can be achieved again and to the consistency of the results, based on Lincoln and Guba's suggestions (1985). They propose the use of an Inquiry Audit to examine the dependability of the research. In an Inquiry Audit, an external evaluator examines the process of the study and its results. The evaluator can point out any deficiencies in the study and propose improvements for the final report. The evaluator will have a different background from the researcher who has completed the study and reported it from his/her own perspective, and thus, depending on the individual evaluator, the point of view may be quite different.

In the case of the present research, external evaluators have been used for each article. The articles have been peer-reviewed, after which the modifications suggested for each of the reports have been implemented. As a result of the peer-reviewing, the quality of the articles has improved when the relevant comments have been taken into account.

5.4.4 Confirmability of the study

Confirmability of research describes the objectivity of the study. Avoiding the bias or motivation of the researcher validates the confirmability of the research itself. According to Lincoln and Guba (1985), the confirmability of a study can be evaluated in terms of four different criteria. In 1) a Confirmability Audit, an external evaluator is used to examine both the results and the process of the study, as in the case of the Inquiry audit described in section 5.4.3. In 2) the Audit Trail, the description of the research stages is presented transparently. This includes raw data, instrument development information, data reduction notes, and other similar material. 3) Triangulation permits checking of the confirmability and also the credibility. The final criterion is 4) Reflexivity, which deals with the impact of the researcher on the study.

Before the intervention of an External Evaluator, all of the results will have been triangulated either by using different data collection methods or by triangulation between analysts. Triangulation has to some degree modified the initial results in every case and the different parts of the triangulation processes have complemented each other.

With regard to reflexivity, the researcher has undoubtedly affected all of the results to some degree. Because of the nature of the research, the impact of the researcher has been visible in the interpretation of the results. Any researcher has his or her own theoretical background and own previous experience, and hence interpretations would differ from one researcher to another, regardless of the same theoretical background being used in the process of analysis. But in the case of the results reported in article III, where pre-service teachers' objectives and experiences were investigated, the researcher has probably had the least implicit influence compared with the other reports. In articles I, II, and IV the researcher has also been the teacher in charge of the course in which the data has been gathered. The ideas and questions put to the course participants by the researcher when he has been functioning as the teacher have almost certainly affected the participants’ own attitudes and methods.

6 Conclusions and outlook

It can be claimed that the theoretical and practical goals of the project have been achieved in the course of this research. Not only has all of articles I-IV expanded the theoretical background of the field of study but each has also provided recommendations for future teacher education.

The studies that resulted in articles I and II enabled us to create a model of the challenges that confront teachers in their planning and implementation of practical work. This model is an important adjunct to the related research and broadens understanding of relevant aspects of the use of practical work.

Article III provided theoretical understanding of the objectives of the practical work that pre-service teachers have formulated during their own school education. Furthermore, we succeeded in locating some of the factors that underlie participants' like or dislike of practical work at school. In brief, pupils tended to regard practical work as a positive experience when they understood the objectives of the experiments, but as a negative experience when the teacher had difficulty in implementing experiments.

The results reported in article IV confirmed some of the statements presented in the literature about the prerequisites for developing teacher knowledge. In addition, the article also describes those aspects of teacher knowledge that can be developed by the use of open guided inquiry in teacher training even at an early stage in teacher education.

The model of the challenges involved in planning and implementing practical work laid out in articles I and II can be directly applied in teacher education. Teacher educators need to understand these limitations and to require their students to confront such challenges so that they can become more aware of them. This also helps pre-service teachers to overcome such challenges and to develop their teacher knowledge further.

The objectives of practical work that pre-service teachers described reveal the deficiencies in their knowledge of practical work. The report in article III could be used in teacher education courses to help pre-service teachers to become more aware of the diverse goals of practical work. This, in turn, would expand their understanding of the importance of practical work in achieving some of the central goals, such as understanding the nature of science itself. The second result, presented in article III, dealing with the reasons underlying positive and negative attitudes to practical work, might also be emphasized in teacher education to indicate the possibility of both success and failure in the use of practical work. We would also expect in-service teachers to benefit from this kind of finding.

In article IV it was noted that the role played by peer discussions was crucial for the development of subject matter knowledge and also, at a later stage, for other significant aspects of teacher knowledge. Context plays a central role by offering pre-service teachers an open environment where they can freely discuss their understanding of subject matter knowledge. As has also been suggested in the literature, teacher education programs need to offer pre-service teachers opportunities for reflecting on their understanding of the content of a discipline (Abd-El-Khalick & BouJaoude, 1997). This, in turn, can lead to consideration of other areas of teacher knowledge.

The research reported in this dissertation also outlines the context for further research. The distinct areas of teacher knowledge need to be examined individually in greater detail in the context described. It could also be argued that the development of subject matter knowledge by means of peer discussions should be studied in greater depth in order to foster similar processes in related theory courses.

The role played by pedagogical studies and teaching practice in forming aspects of physics teachers' teacher knowledge might also provide a significant area of study. As yet, there is no clear model outlining the aspects of teacher knowledge that would deserve to be developed by each educator. It would help to consolidate collaboration between participants in physics teacher education if all parties could point out the aspects of teacher knowledge that they have focused on in particular. In addition, there is also a need for a longitudinal study in which the development of teacher knowledge is examined from the point of view of pre-service teachers in the course of their studies in physics, education, and teaching practice.

In closing, there is also the question of whether, and then how, pre-service teachers can apply their knowledge of practical work at school after graduating as teachers when they have undergone this kind of education at university. It would be valuable to understand the various different views of practical work that pupils develop when they have been taught by teachers who have graduated from our teacher education program.

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Ville Nivalainen

Pre-Service Teachers' Objectives, Challenges, and Experience of Practical Work

This thesis focuses on the use of practical work in the context of physics teacher education. The pre-service teachers' understanding of the objectives of practical work, as well as their experiences of practical work at school and university are studied. Furthermore, pre- and in-service teachers' challenges in the planning and implementing of practical work are examined. These aspects are discussed in the fostering of teacher knowledge. Implications of the study are given to teacher education programs.

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